APPLE ATTITUDE ACQUISITION WITH ONE SOLAR PANEL UNDEPLOYED

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Abstract. One of the two solar panels on the APPLE Spacecraft had failed to deploy. The paper presents an analysis of the difficulties arising out of this problem from the point of view of the attitude control system, in particular for sun acquisition and the procedures adopted to overcome these difficulties leading to successful attitude acquisition.

Keywords. Attitude control; attitude acquisition; control system analysis.

INTRODUCTION

APPLE (Ariane Passenger Payload Experiment) is India's first 3-axis stabilized geostationary experimental communication satellite. It has two C-band transponders to carry out experiments on TDMA, SSMA, computer networking and to provide TV and voice communication links on an experimental basis. It was successfully launched on June 19, 1981 by the third developmental flight of ESA's Ariane launch vehicle. The overall features of the APPLE Spacecraft are given in the Appendix.

Following ABM firing, conventional techniques of attitude acquisition was to have been employed. The sun acquisition was to be done with the help of the 4π steradian coarse sun sensor and then the fine sun sensor and subsequently earth acquisition was to be done at around 6 a.m. spacecraft local time. Due to configurational difficulties, the segments of the 4π steradian sensor were covered by the two stowed North and South solar panels. Upon deployment of both the panels, the sensor enables to define the sun line in the body-fixed frame for any random orientation of the spacecraft. The sensor also provides a sun presence signal (SPS) which identifies the East face of the spacecraft. The SPS is used to enable the outputs of the acquisition controller to actuate the thrusters. This effectively inhibits the region of positive damping thereby facilitating quick capture. The SPS is normally available upto $\pm 90^{\circ}$ rotation of the roll axis in the roll-pitch (R-P) and the roll-yaw (R-Y) planes.

However, a problem developed during the initiation of the acquisition sequence when one of the two solar panels failed to deploy. This necessarily forced a departure from the nominal sequence. The paper presents an analysis of the difficulties arising out of this problem from the point of view of the attitude control system, in particular for sun acquisition and the procedures adoptec to overcome these difficulties leading to successful attitude acquisition.

THE PROBLEM OF PANEL NONDEPLOYMENT

After ABM firing (22.49 UT, June 21, 1981), the next phase of operations consists essentially of suitably orienting the space craft axes. The first step was to reduce the spin rate (about the yaw axis) from around 65 rev/min to 5 rev/min and orientin the spin axis such that the aspect angle wa close to 90° (1.02 UT, June 22, 1981). The spin rate was subsequently reduced to aroun 0.5 rev/min.

The solar panel deployment was initiated at 02.50 UT, on June 22, 1981. When the SPDM (Solar panel deployment mechanism) fire command was given, the telemetry informatioı about the status of the yoke and panel micrc switches indicated that neither panel had deployed. The spacecraft was spun up to 1 rev/min and the South yoke microswitch indication came on and the 4π steradian sensor yaw negative output confirmed that the South panel had deployed. The spacecraf was further spun up to 5 rev/min. However, from the 4π steradian yaw output, the panel microswitch indication and thermal profile, it was evident that the North panel had not deployed at all. Consistent efforts to deploy the North panel including spinning up the spacecraft in steps upto 24 rev/min were of no avail. The spacecraft was then despun to 10 rev/min (11.44 UT, June 22, 1981) and left in the spin stabilized mode.

The next step was to study the problem created by the stowed North panel with specific reference to the sun acquisition manoeuvre. As mentioned earlier, this manoeuvre was to

have been initiated using the 4π steradian sun sensor, the locations of its four segments being shown in Fig.1.

Had both the panels been fully deployed, the sensor would have the characteristics shown in Fig.2. The sun presence signal merely indicates whether the positive roll axis is in the eastern half or western.

Figure 1 also shows that the stowed north panel covers the north segments of the sensor. It was estimated that the yaw output from this sensor could not be obtained on the positive side beyond 30^{o} (Fig.3). This also means that the sun presence signal (for the positive roll axis to be in the Eastern half) would exist for yaw errors within the interval -90^{o} to $+30^{o}$. This signal is used to enable the yaw and pitch controller outputs to the thruster drivers so that thruster operation is inhibited when this signal is absent.

THE FIRST ATTEMPT AT SUN ACQUISITION

The 4π steradian sensors are supplemented by a fine sun sensor mounted on the east face of the spacecraft. This sensor measures the angle between the sun line and the east face in the R-Y and R-P planes, but has a limited coverage of $\pm 40^{o}$ in each plane (Fig.4). Because of the problem mentioned above, it was decided to carry out the sun acquisition directly with the fine sun sensor by first ensuring that the angle between the sun line and the yaw axis is nearly 90^{o}.

Hence, the spacecraft was first despun to 5 rev/min (22.58 UT, June 22, 1981) and the spin axis (yaw axis) oriented such that the aspect angle was close to 90^{o}. The spacecraft was then further despun to about 0.5 rev/min in order to proceed with the sun acquisition. The yaw and pitch closed-loop controllers in the acquisition modes with the fine sun sensor were switched on (0.52 UT, June 23, 1981). However, the roll axis failed to lock on to the sun. The controllers were switched off and switched on again when the sun came into the field of view of the fine sun sensor. Once again the roll axis failed to lock on to the sun and the controllers were switched off. The spin rate about the yaw axis was then increased by 0.5 rev/min (2.39 UT, June 23, 1981) in order to stabilize the spacecraft.

An Important Observation: A clue to the failure of the first attempt at sun acquisition was provided by an observation of the sun transit sensor output. It was found out by noting the interval between the sun transient pulses that the spin rate about the yaw axis had increased to about +2.5 rev/min. This undesired increase in the spin rate indicated that the controller was not able to provide sufficient damping on the positive yaw error side within the limited availability of the sun presence signal.

A Quick Analysis of the Problem:

A study shows that when the yaw error is between -50^{o} to -40^{o}, the fine sun sensor characteristic has a rather steep negative slope and this region provides a significant positive feedback to the closed-loop yaw controller. As a result, the yaw rate increases. The negative feedback region for yaw errors between -40^{o} to $+40^{o}$ acts to reduce the rate. However, for positive yaw errors, the limited availability of the sun presence signal, in turn, limits the yaw loop controller action yielding a net increase in the spin rate (Fig.5a).

It was realized that this problem of the net yaw rate increasing would persist for any positive initial spin rate. However, if the initial spin rate were to be negative (i.e. spin about negative yaw axis), the controller operates in the negative feedback region (positive sensor slope) right from the start and hence the likelihood of error convergence exists (Fig.5b), provided, of course, that the initial negative rate is sufficiently small.

SUCCESSFUL SUN ACQUISITION

The spacecraft was despun to about -0.4 rev/min and the pitch and yaw loop controllers were switched on (3.24 UT, June 23, 1981) as soon as the sun was found to be in the field of view of the fine sun sensor with the hope that the asymmetric sun presence signal might yet allow the controllers to provide adequate damping for sun acquisition. As was anticipated, the roll axis got aligned with the sun line leading to successful sun acquisition. This was achieved at around 06.10 hours spacecraft local time.

The next step was to enable the deployed solar panel to track the sun. This operation lasted about 15 minutes, thereby making the subsequent earth acquisition manoeuvre rather time critical.

FIRST ATTEMPT AT EARTH ACQUISITION

The earth acquisition manoeuvre consists of switching on the roll-loop controller with the earth sensor providing the roll error when the earth is in the field of view of that sensor, and subsequently switching over the pitch loop controller from the fine sun sensor to the earth sensor. However, since the earth presence signal (EPS) was not immediately observed, a series of torque pulses were provided to generate enough roll rate so as to hasten the process of obtaining the earth within the field of view of the earth sensor. The EPS was observed at

around 06.35 hours satellite local time and the roll loop controller was switched on (4.04 UT, June 23, 1981) and in view of the limited time available, the earth sensor was selected for the pitch loop controller almost immediately. However, the EPS was lost and the pitch controller was reverted back to the fine sun sensor. The EPS was not observed again and finally, the acquisition controllers were put off (4.18 UT, June 23, 1981). Since the earth acquisition could not be achieved , the solar panel rotation was inhibited and the spacecraft was spun up by about 1 rev/min (4.22 UT, June 23, 1981) to be left in the spin stabilized mode.

An Anomaly:

In preparation for a spin axis orientation correction to bring the sun aspect angle close to 90°, the spacecraft was spun up by 5 rev/min (10.13 UT, June 23, 1981). However, a computation of the spin rate indicated that it had gone as high as 24 rev/min.

This increase in the spin rate can be explained as follows. The pitch controller had been switched on to the earth sensor at about the time the sensor was crossing the earth's edge. But the EPS appeared to be present through the telemetry data as the sampling rate of the signal is very slow (once in 64 secs), although it might have disappeared immediately after switching the pitch loop to the earth sensor. When the earth sensor is not seeing the earth, it gives a saturated pitch output. Hence, for about a maximum of three minutes, before the pitch loop was switched back to the fine sun sensor, the pitch controller output was continuously 'ON', giving rise to an increase in the pitch rate which eventually resulted in the spacecraft spinning about the yaw axis (maximum moment of inertia axis).

SUCCESSFUL ATTITUDE ACQUISITION

The spacecraft was despun in steps to about 6.5 rev/min and the sun aspect angle was brought close to 90°(19.03 UT, June 23, 1981).

In preparation for the sun acquisition manoeuvre, the spacecraft was further despun to about -0.2 rev/min. The yaw and pitch controllers were switched on with inputs from the fine sun sensor (20.00 UT, June 23, 1981) and as expected, the spacecraft roll axis got aligned with the sun line. The solar panel tracking was then initiated.

A series of torque pulses about the roll axis were given to increase the roll rate and as soon as the earth appeared in the field of view of the earth sensor, the roll controller was switched on (0.35 UT, June 24, 1981). When the yaw got locked on to the earth, the pitch controller was switched over to the earth sensor. That completed the earth acquisition.

Subsequently, the primary momentum wheel was put on and when its speed reached its nominal value of 3500 rev/min, it was put in the torque control mode of operation and finally the thruster control was switched off.

SIMULATION RESULTS

A computer simulation study has subsequently been conducted on the effect of the limited availability of the sun presence signal (SPS) on the convergence of the sun acquisition scheme.

Simulations were carried out for initial spin rates of +0.2 rev/min and -0.2 rev/min assuming that the SPS is available for positive yaw errors upto +10°, +20° and +30° respectively, and the results are presented in Fig.6, in the form of phase-plane plots. The plots clearly illustrate the lack of convergence with the positive spin rate and even for the negative spin rate of -0.2 rev/min if the SPS is limited to only +10° of yaw error.

CONCLUSIONS

The non-deployment of one of the two solar panels of the APPLE Spacecraft had posed a problem for its attitude acquisition. It was important that sun acquisition be achieved in the shortest possible time because the situation was becoming critical from the point of view of power availability and the associated drain on the battery. Any errors committed at that stage would very well have resulted in the loss of the spacecraft. The paper has highlighted the difficulties arising out of the problem, the quick analysis carried out and the solution which eventually resulted in successful attitude acquisition. Results of subsequent simulation studies to validate the analysis have also been provided.

ACKNOWLEDGMENTS

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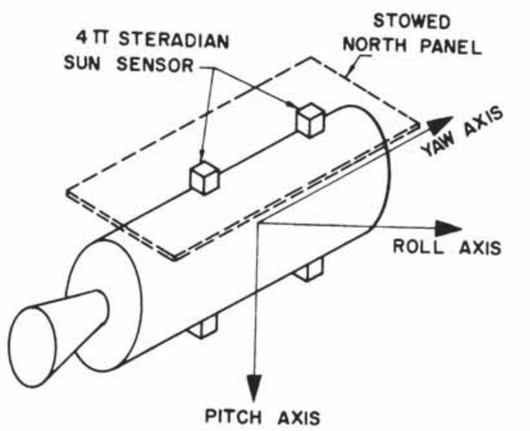

Fig. 1. Stowed North Panel on APPLE

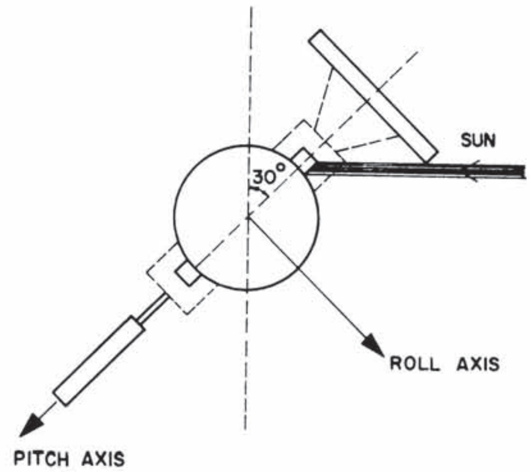

Fig. 3. Effect of the Stowed Panel

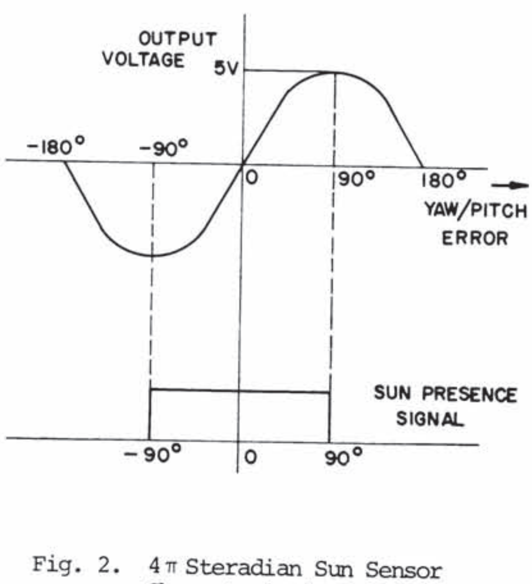

Fig. 2. 4π Steradian Sun Sensor Characteristics

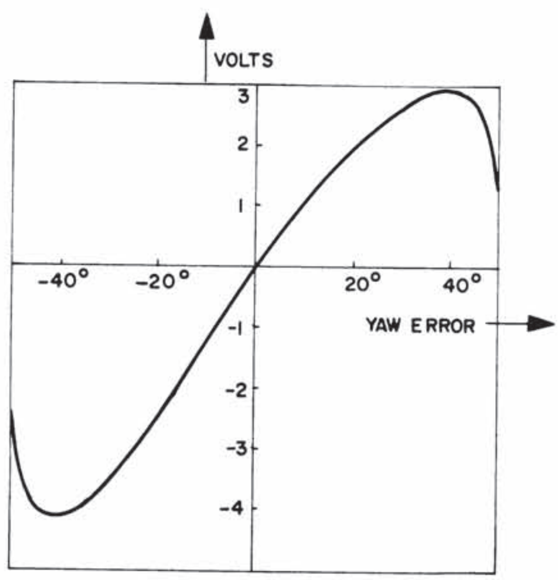

Fig. 4. Fine Sun Sensor Characteristics

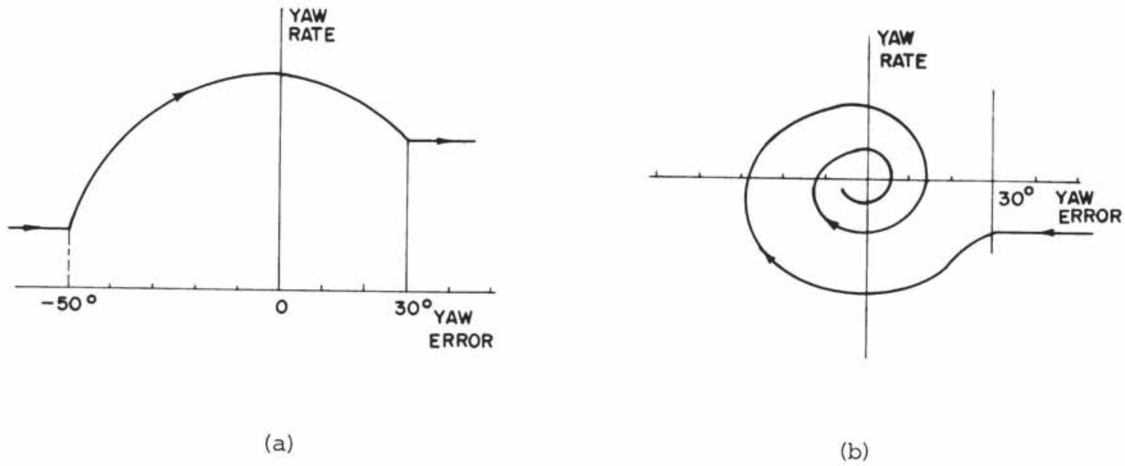

Fig. 5. Effect of the Limited Availability of the SPS

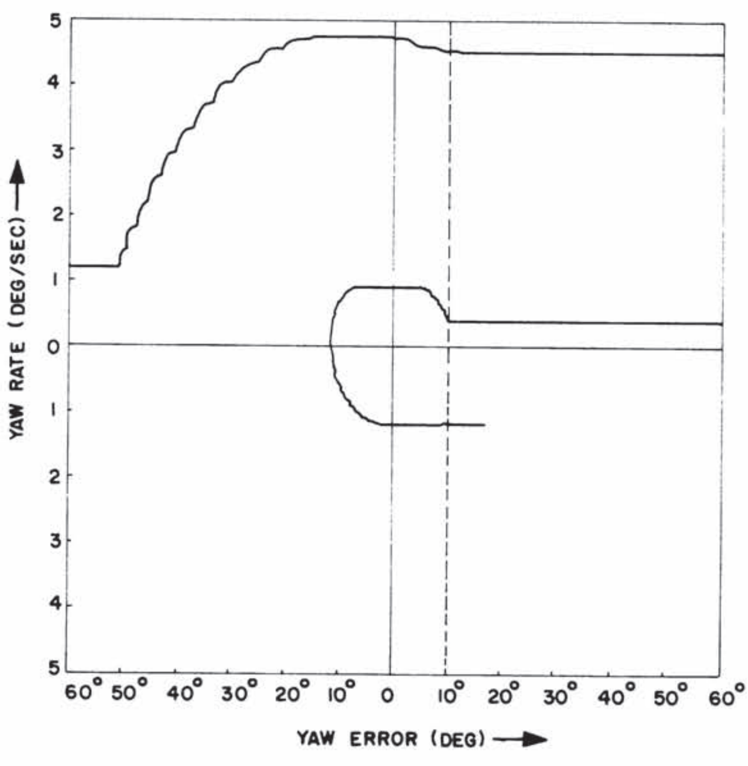

Fig. 6(a). Simulation Results

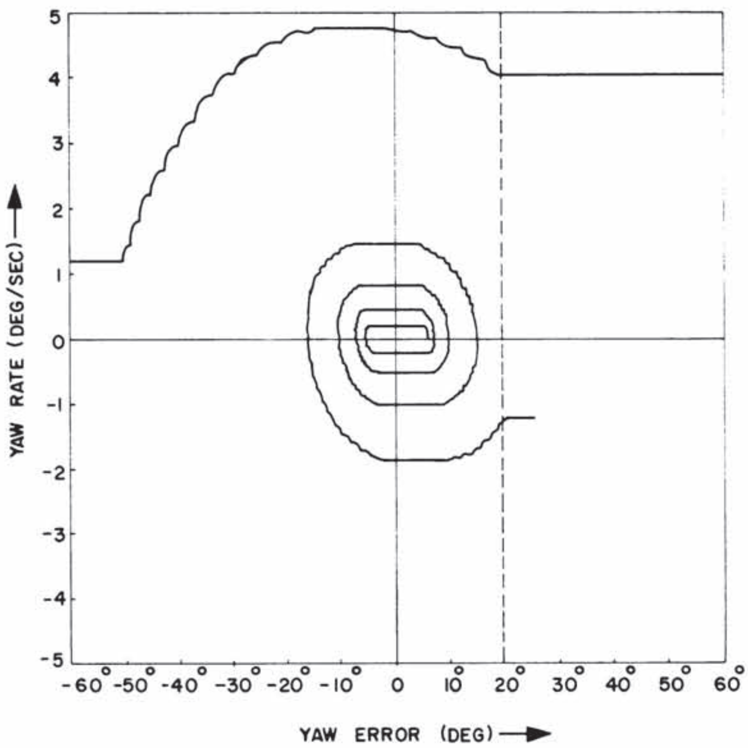

Fig. 6(b). Simulation Results

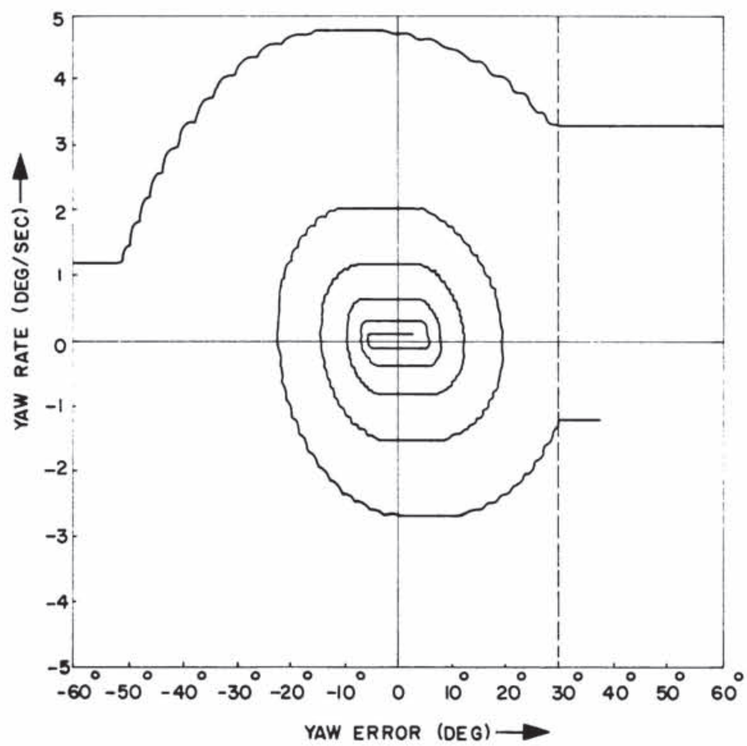

Fig. 6(c). Simulation Results

APPENDIX

OVERALL FEATURES OF THE APPLE SPACECRAFT

Type:

Experimental body-stabilised communication satellite;

Orbit:

Geostationary. Sub-satellite point 102°E longitude

Life time:

Two years (constrained by the hydrazine loading)

Mechanical characteristics:

Weight at launch	:	672 Kg
Weight in orbit	:	380 Kg
Body dimensions	:	1200 mm dia and 1200 mm height cylindrical shell 1985 mm overall height 4665 mm across deployed solar panels.

Electrical Power Supply:

Driven deployable solar panels on North-South and

Chemical Storage Battery	:	300 Wh
Maximum array power at BOL	:	280 W
Maximum array power at EOL	:	210 W

Telemetry, Tracking & Command (TTC):

Telemetry	:	137.292 MHz / 4.095 GHz (Transfer Orbit)/(on station) PCM/FM/PM 64 bps
Telecommand	:	140.522 MHz PCM/FSK/AM 202 ON/OFF commands +9 Data commands
Tracking	:	Crystal coherent VHF transponder. Also a C-band beacon at 4095 MHz

Attitude Control:

3-axis body-stabilised with redundant momentum wheel system and hydrazine reaction control system for attitude control and station keeping. Sun tracking system for solar panels.

Insertion into synchronous Orbit:

Injected into near synchronous orbit from a transfer orbit of 200 x 35786 KM by a solid propellant apogee boost motor (ABM) with an incremental velocity of 1532 m/sec.

Communications sub-system:

One transponder with full redundancy.
Travelling Wave Tube (TWT) output Power Amplifiers.

Receive Frequency Band	:	6385 ± 20 MHz
Transmit Frequency Band	:	4160 ± 20 MHz
Radiated Power (EIRP)	:	31.5 dBW (peak)

Communications Antenna:

900 mm diameter paraboloidal CFRP reflector with prime-focus feed.